Shoulders….
Not Just for Snow Storage!

Purdue Road School

March 5, 2019

BURGESS & NIPLE
Engineers ■ Architects ■ Planners

Ideas in motion.

Agenda

- What is HSR?
- Where is HSR Implemented?
- Analysis Considerations
  - Traffic
  - Safety
- Cost Considerations
- Design Considerations
- Implementation
- Operations
- Other State's Lessons Learned
- Screening Process

What is HSR?

What is HSR?

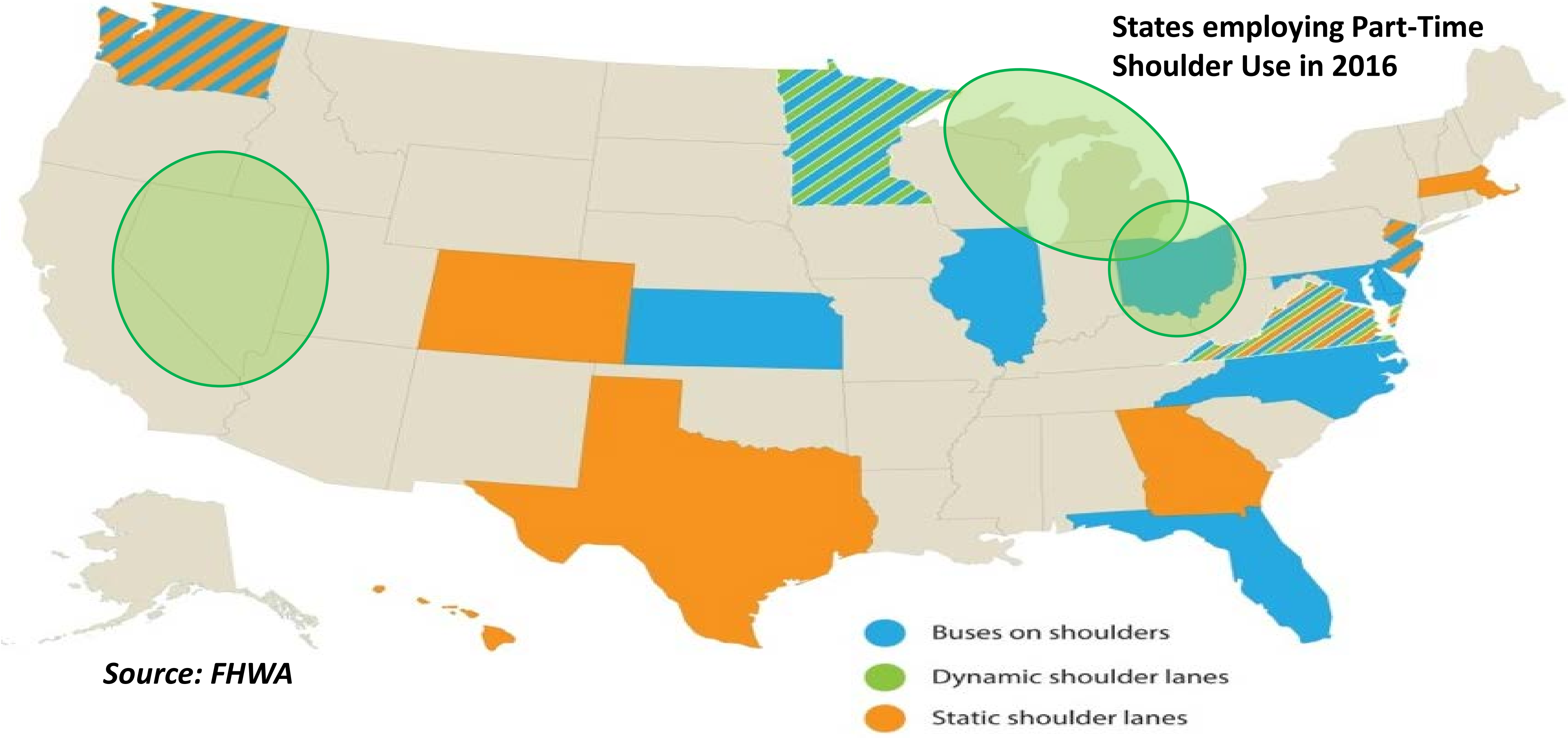
- The use of the left or right safety shoulder of an existing roadway for travel *during certain hours of the day*
- Preserves shoulder as shoulder during most hours of the day; *not a permanent conversion of the shoulder*
- A TSM&O strategy for addressing congestion and reliability issues; adds capacity only when needed
- Various Names
  - Hard Shoulder Running
  - Shoulder Running
  - Temporary Shoulder Use
  - Part-Time Shoulder Use

Different HSR Concepts

- **Left vs. Right**
- **Dynamic vs. Static**
- **Vehicle-Use Options**
  - **All vehicles**
  - **Transit only**
  - **Prohibit trucks**
  - **HOV/HOT**
- **Speed Control Options**
  - **Same speed (as posted)**
  - **Reduced speed**

Where is HSR Implemented?

Where is HSR Implemented?



Source: FHWA

Where is HSR Implemented?

I-66 in Northern Virginia – Dynamic; Right Side

NJ Turnpike – Static; Right Side

Where is HSR Implemented?

US 2 in Everett, Washington – Static; Right Side

US 23 in Ann Arbor, Michigan – Dynamic; Left Side

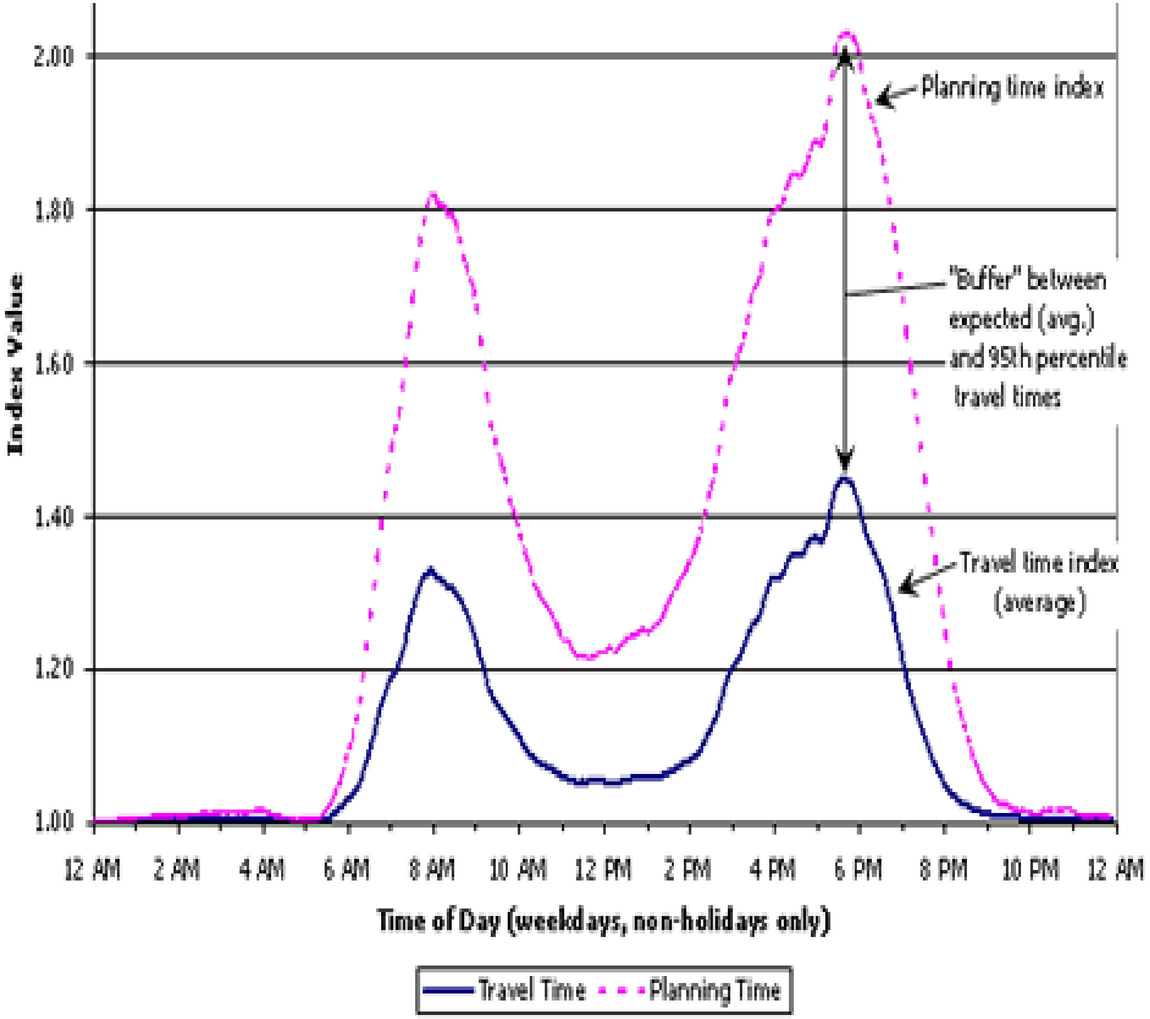
Analysis Considerations

Traffic Analysis

- **Increased Capacity**
  - **Shoulder capacity ranges between 1,000 and 1,650 vehicles per hour**
  - **Dependent on geometric conditions and level of communication to the driver**
  - **Left shoulder capacity is slightly higher than the right shoulder**

Traffic Analysis

- Increased Reliability
  - Travel times are more consistent on a daily basis
  - Less buffer time required to ensure on-time arrival
  - More predictable for users

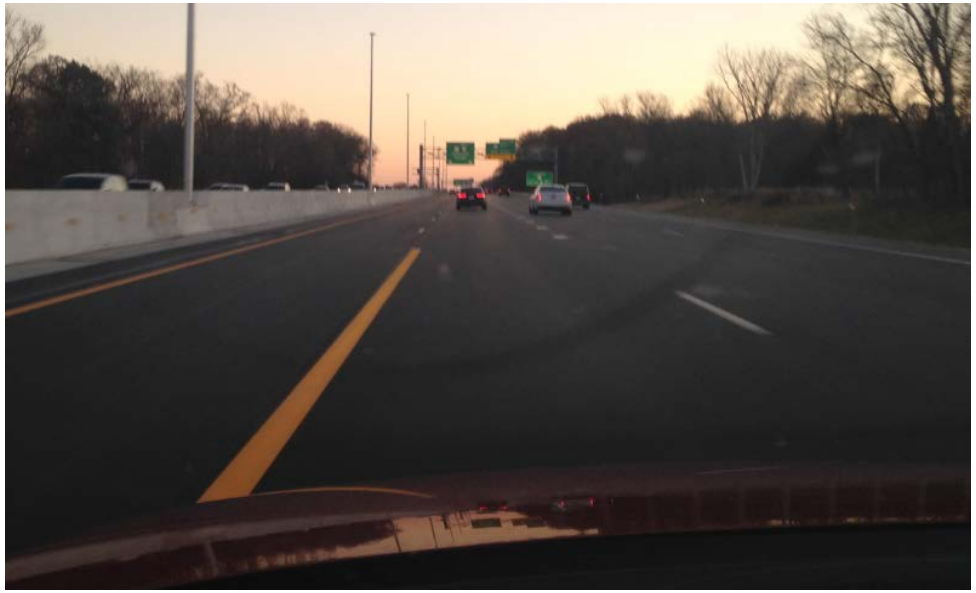


Appropriate Length of HSR

- **Typically Used on Long Segments That Include Multiple Interchanges**
  - **Commuter corridors with recurring congestion**
  - **Used to avoid expensive widening over long corridors**
- **Can Be Used on Acute Bottlenecks**
  - **Georgia and Hawaii use as auxiliary lanes between interchanges**
  - **Termination method is critical to avoid queues**

HSR Lane Termination

- **End on Basic Freeway Segment as a Lane Drop**
  - HSR lane merges into adjacent travel lane; ideally at a location where number of mainline lanes are adequate for traffic volume
  - Potential to cause queues at merge point
- **End by Dropping HSR Lane to Interchange Ramp**
  - HSR lane terminates into an exit-only lane at the interchange
  - Ideally a high-volume exit ramp
  - Creates a smooth transition of the HSR

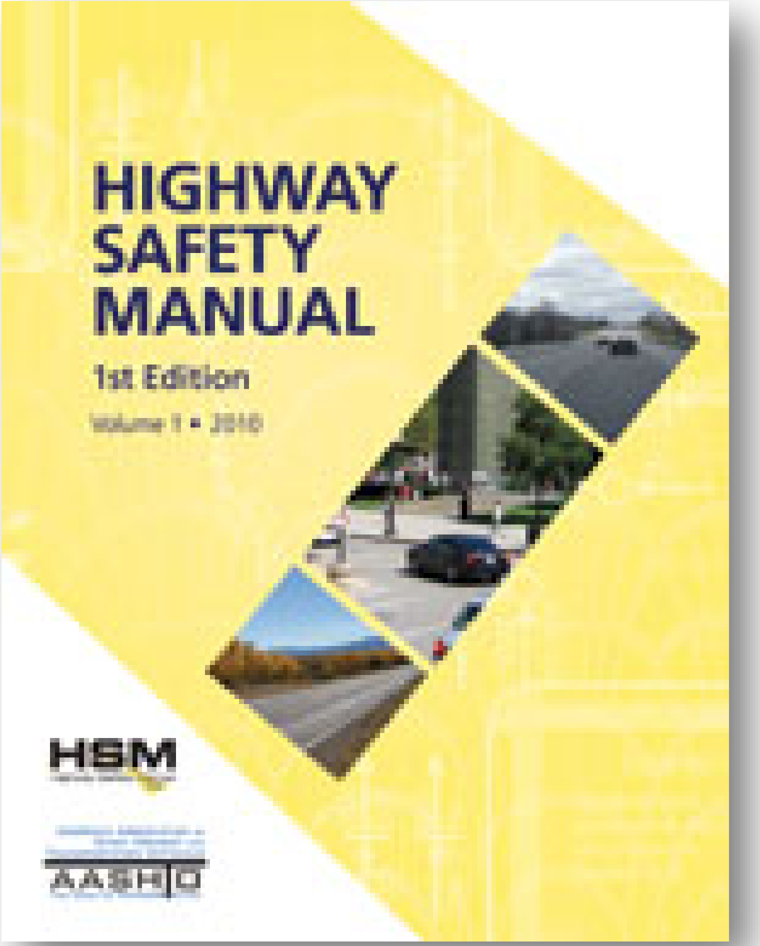


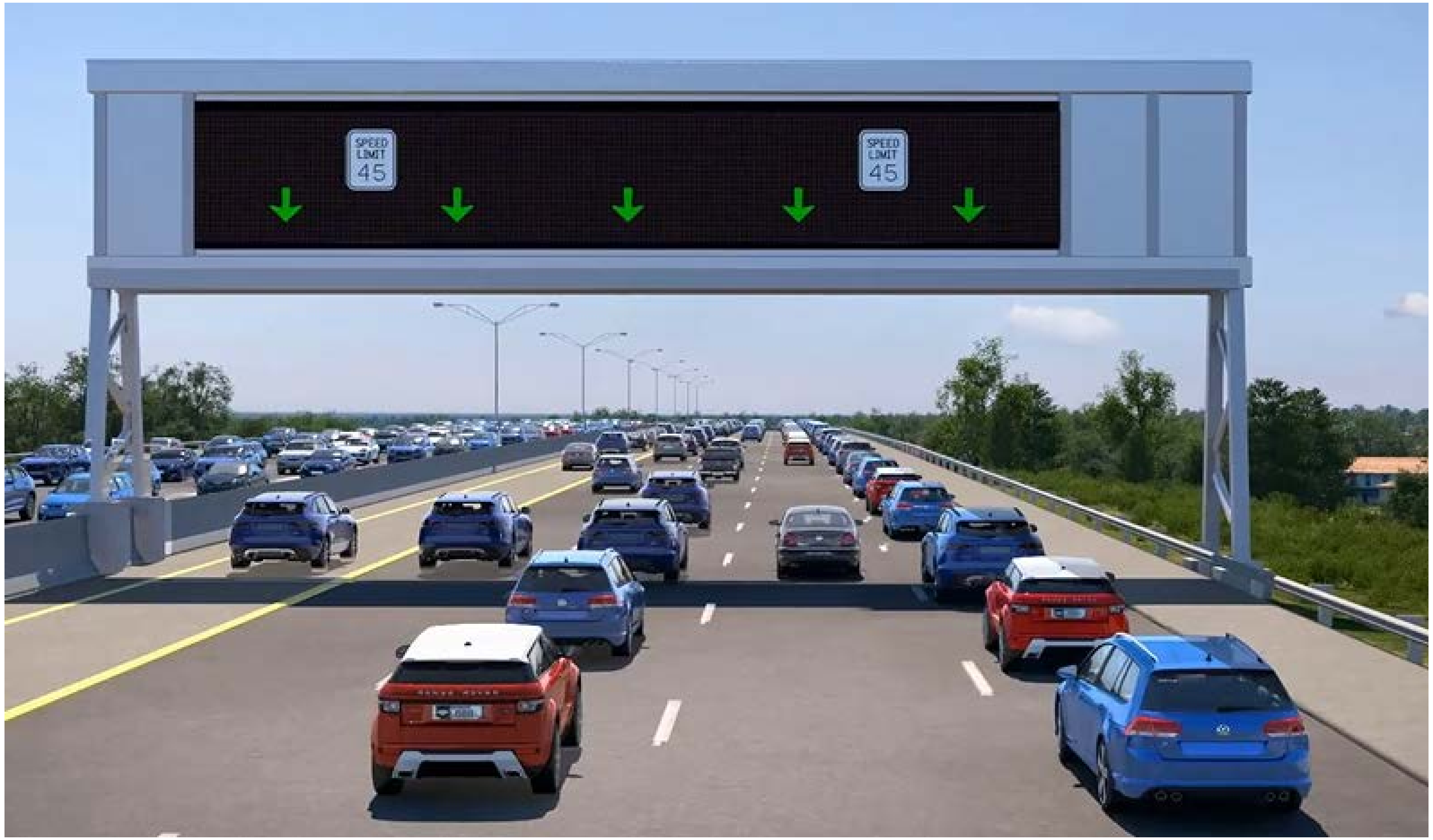
Traffic Analysis Summary

- **HSR Lane Capacity Lower than Freeway Lanes**
- **Highway Capacity Manual (HCM) Analysis**
  - **Cannot adjust capacity on per-lane basis**
  - **Determine new capacity value for the freeway segment**
- **Microsimulation (VISSIM, TransModeler) Analysis**
  - **Can assign capacity and speed on a per-lane basis**
  - **Can prohibit different vehicle classes in HSR lane**
  - **Great tool for public meeting**
- **Recommendation: Use HCM for preliminary analysis and microsimulation for final alternative**

Safety Analysis

- **How do you predict how HSR will affect safety?**





Safety Analysis – Case Study in Ohio

- Ohio's HSR Project
  - Left Side
  - Static Operation (4-6pm)
  - Variable Speed Limit (45mph)
  - Existing Left Shoulder (14-16 ft)
  - HSR Lane Width (11.5 ft)
  - Median barrier adjacent to HSR lane
  - When HSR is open, barrier is 3.5-5 feet away from the lane

How do you think the Safety Numbers will look??

Safety Analysis – Case Study in Ohio

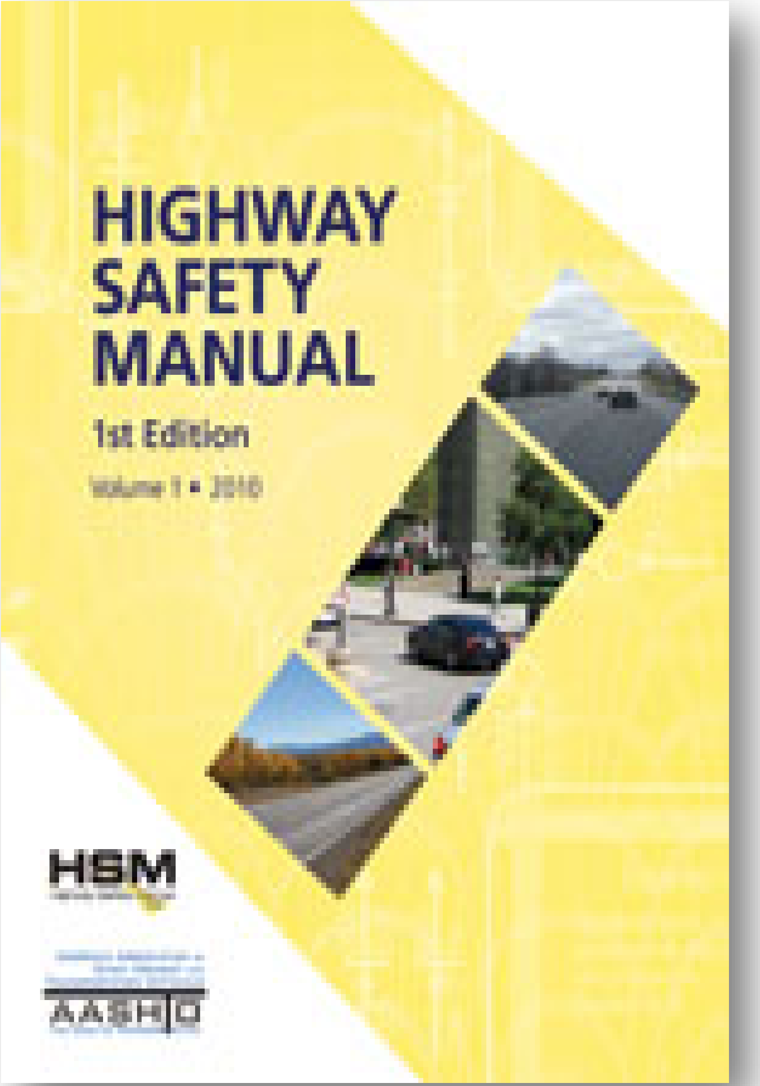
- **Initial** HSM Analysis Results

	KA	B	C	O	Total
No Build	6.5	22.0	23.2	137.1	188.9
Build	7.1	23.1	24.3	142.0	196.5
Difference	**+0.6 (8%)**	**+1.1 (5%)**	**+1.1 (5%)**	**+4.9 (4%)**	**+7.6 (4%)**

K – Fatal; A – Incapacitating Injury; B – Nonincapacitating Injury; C – Possible Injury; O – Property Damage Only

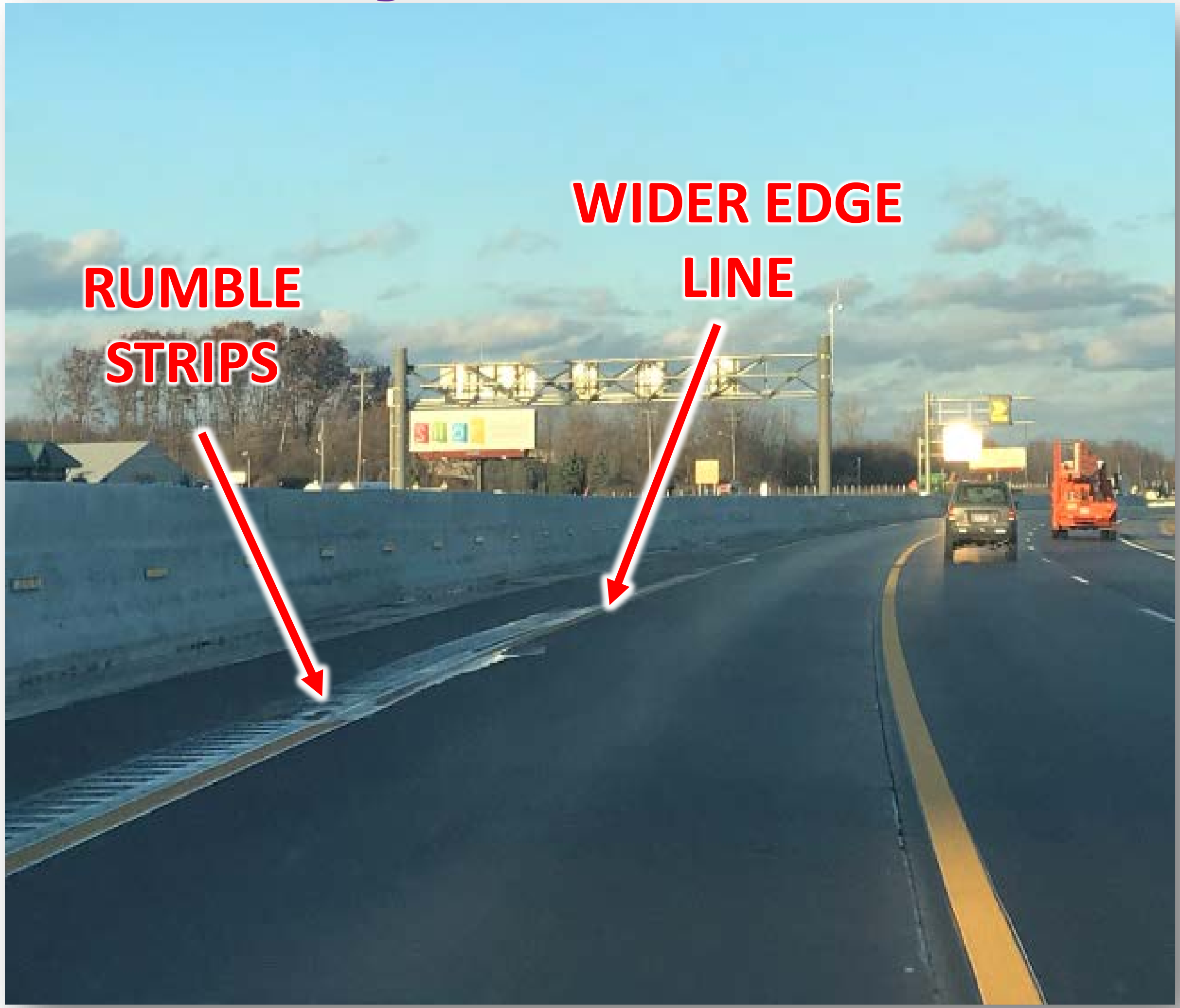
Safety Analysis – Case Study in Ohio

- **Holes in HSM Analysis**
  - **HSM assumes 24-hour analysis**
    - **HSR is only operational for a few hours per day**
  - **HSM does not account for speed**
    - **HSR is only operational when speeds are lower than free-flow speeds (congestion)**



Safety Analysis – Case Study in Ohio

- **Countermeasures to prevent fixed object crashes**
  - Rumble Strips
  - Wider Edge Lines
  - Median Barrier Reflectors



Safety Analysis – Case Study in Ohio

- **Final** HSM Analysis Results (with countermeasures)

	KA	B	C	O	Total
No Build	6.5	22.0	23.2	137.1	188.9
Build	5.7	18.5	19.5	142.0	185.7
Difference	**-0.8 (13%)**	**-3.5 (16%)**	**-3.7 (16%)**	**+4.9 (4%)**	**-3.2 (2%)**

K – Fatal; A – Incapacitating Injury; B – Nonincapacitating Injury; C – Possible Injury; O – Property Damage Only

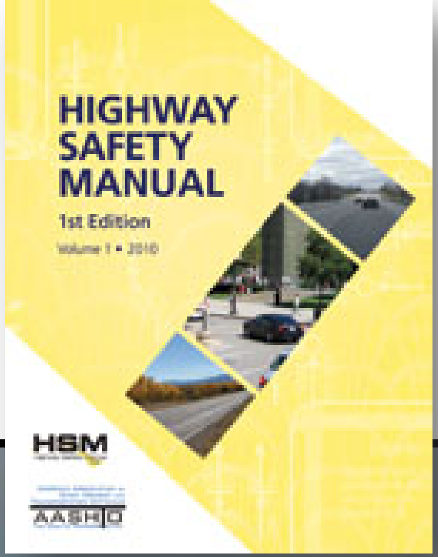
Safety Analysis – Case Study in Ohio

- **What do other studies say?**
  - **HSR Would Likely Reduce Congestion-Related Crashes**
    - Rear-End
  - **HSR May Increase Crashes Related to Erratic Driver Behavior or Sub-Optimal Geometry**
    - Fixed Object
    - Run-Off-Road
    - Sideswipes

Corridors with High Percentage of these Crash Types May Not be Good Candidates for HSR

Safety Analysis

- **Summary of Safety Analysis**
  - HSM Analysis is good, but not perfect
  - Additional countermeasures may be necessary
  - Review corridor crash patterns before implementation
  - Audits have shown safety performance of facilities with HSR is comparable or better



Cost Considerations

Cost Considerations of HSR

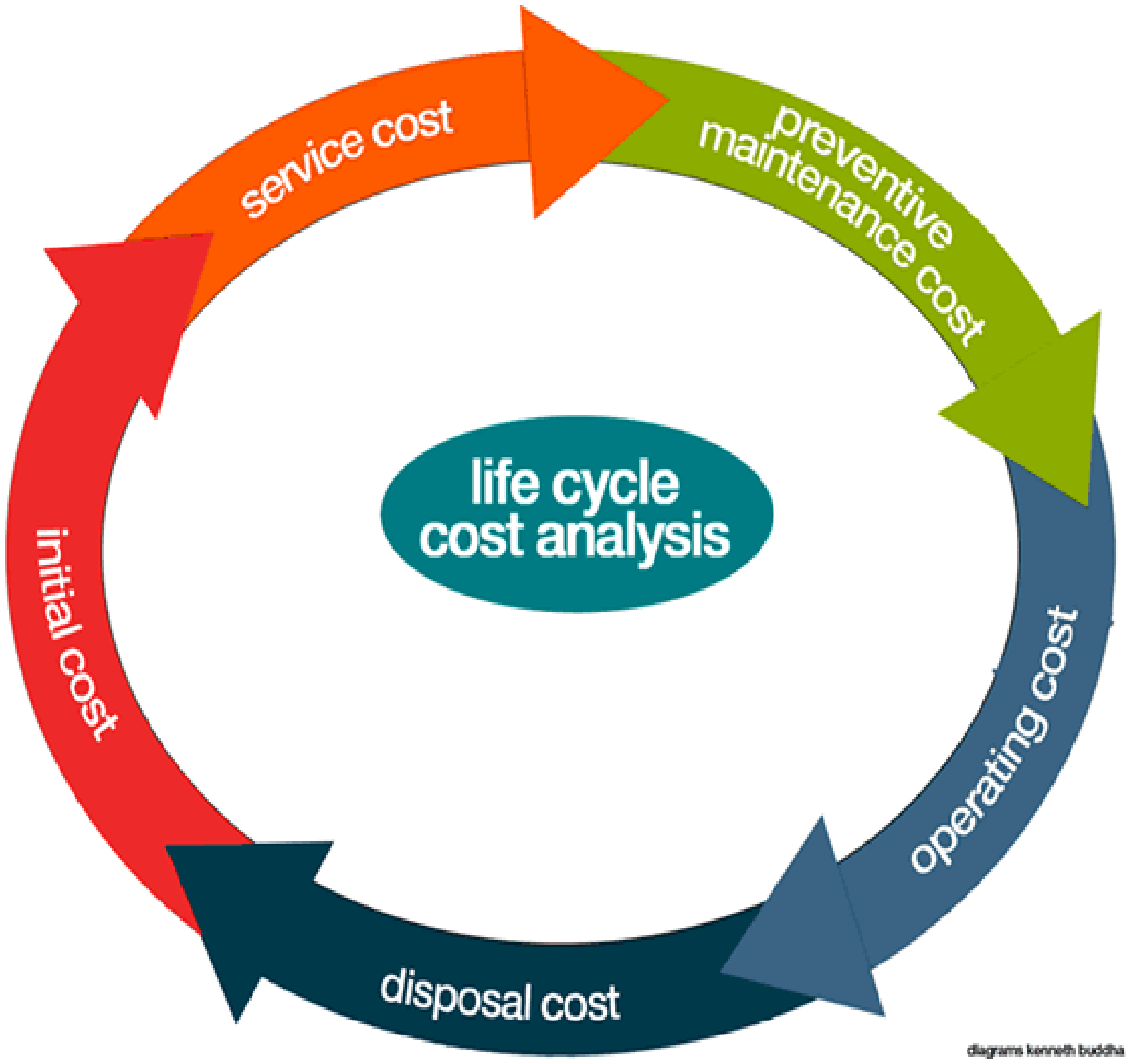
- Compare to Traditional Improvements
  - Often less upfront capital cost by often as much as 50%!
  - Re-use existing infrastructure saves $$
    - Full-Depth Existing Shoulders
    - Existing Fiber Backbone
    - Existing Freeway Management System

However………

- HSR typically incur a greater proportion of costs as continuing operations and maintenance
- ITS infrastructure often has a much shorter anticipated useful life than traditional improvements
- Could result in future funding gaps or the inability to properly operate and maintain system

Benefit/Cost Analysis of HSR

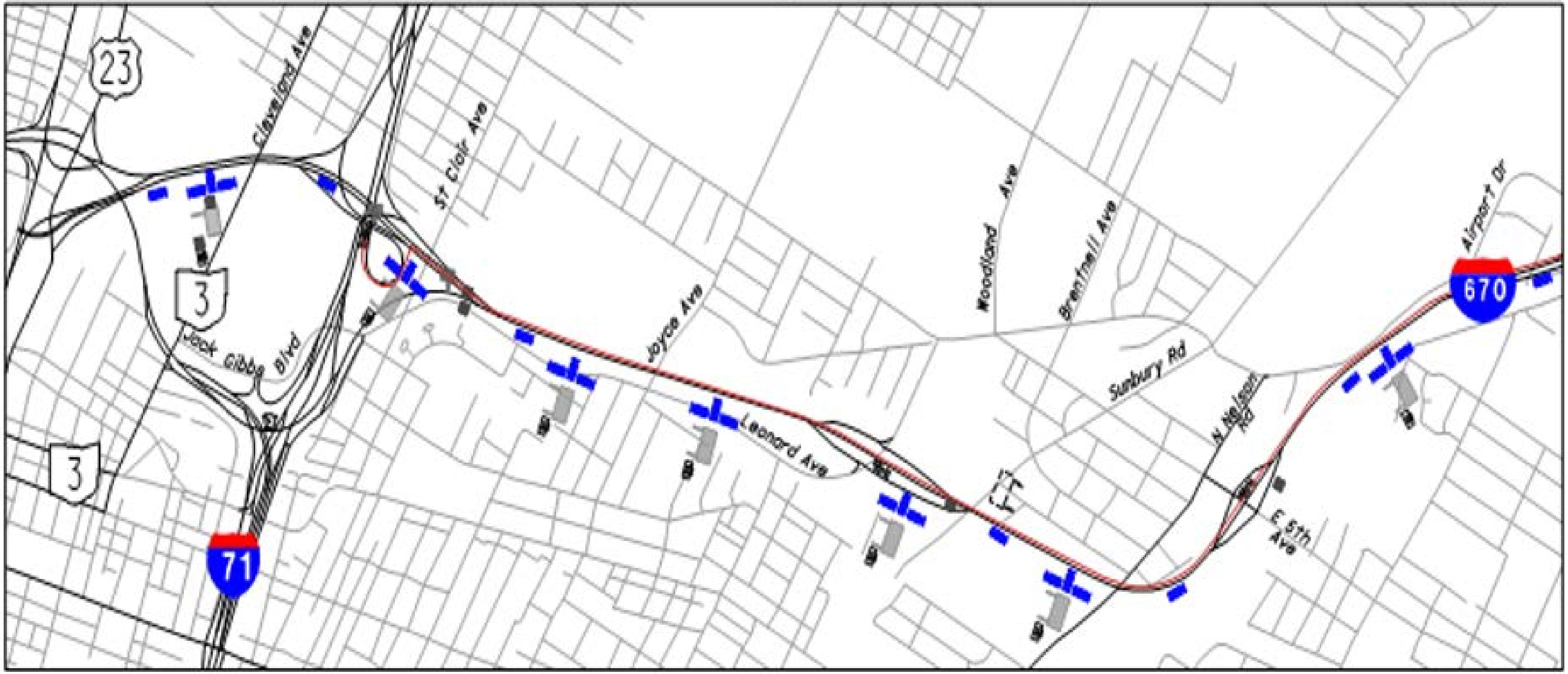
- **Include the following for Costs:**
  - ***Capital Cost* – upfront cost of project improvement**
  - ***Operations & Maintenance Cost* – continuing cost necessary to operate and maintain, including labor costs for activities such as emergency patrols & TMC staff**
  - ***Replacement Cost* – periodic cost of replacing or redeploying equipment as it becomes obsolete and reaches an end of its expected useful life**



Design Considerations

ITS Design – CCTV Cameras

- **No Blindspots**
  - **Number of cameras depends on horizontal geometry (curves), vertical geometry, bridge overpasses, overhead signs**



ITS Design - Gantries

- **Spacing Varies Between ½ and 1 Mile**
  - Function of existing overhead guide sign locations and overhead bridge crossings
  - Number of ramps
- **Spacing Depends on their Function**
  - Speed Harmonization
  - Incident Management
  - Dynamic Operation

Recommendation: Walk the corridor early in the project and identify preliminary locations of gantries

ITS Design – Dynamic Message Signs

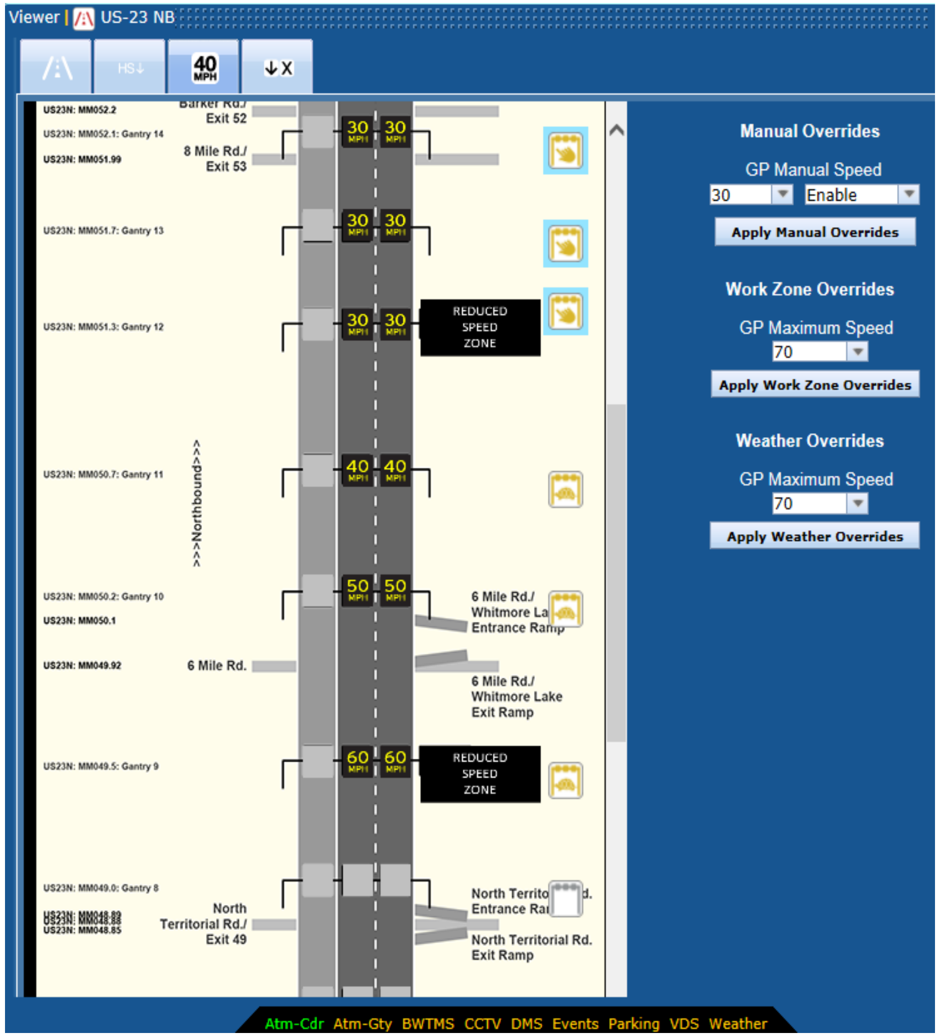
- **Several Options**
  - **Individual Bricks**
  - **Full-Width Signs**
- **Mounting Options**
  - **Truss**
  - **Cantilever**

ITS Design – Put It All Together

HSR Software

- The system can get complicated quickly
- The TMC personnel need to manage it
- The software must be user-friendly
- Budget for training of personnel
- Budget for testing in the schedule

HSR Software



Geometric Design

Controlling Criteria	Minimum AASHTO Values[37, 38, 39]	Affected by Part-time shoulder use
Design Speed	Chosen by agency. Shall be at least 50 mph in urban areas, should be 70 mph in rural areas, may be 50-60 mph in mountainous areas	No, unless agency choses to reduce it
Lane Width	Shall be 12 feet	Possibly
Shoulder Width (values for paved width presented)	4-lane freeways – Right shoulder shall be 10+, left shoulder shall be 4+ feet 6+-lane freeways – both shoulders should be 10+ feet Truck traffic exceeds 250 DDHV – 12+ foot shoulders on both sides should be considered	Always
Bridge Width	Less than 200 feet long – Shall equal full paved width of approach roadway 200+ feet long, Green Book – provide approach shoulder widths and median barrier if single structure. 200+ feet long, Interstate Standards – offsets to parapet, rail, or barrier shall be 4+ feet from travel lane	Likely
Horizontal Alignment	Varies based on design speed and maximum superelevation (see Green Book Table 3-7)	Possible
Superelevation	Maximum of 6 to 12 %, should consider maximum of 6 to 8 % where snow and ice are a concern	Possible
Vertical alignment	Varies based on several elements (see Green Book Figure 3-43 for sag curves and 3-44 for crest curves)	Never
Grade	Varies 3 to 6% by type of terrain and design speed (See Green Book Table 8-1)	Never
Stopping Sight Distance	Varies based on design speed and grade (See Green Book Table 3-1 and 3-2)	Possibly
Cross slope	Green Book – 1.5 to 2 % Interstate Standards – Shall be 1.5% minimum, desirably 2%, may be 2.5% in areas of intense rainfall. Shoulder slopes should be in range of 2 to 6 %	Possibly

Controlling Criteria	Minimum AASHTO Values[37, 38, 39]	Affected by Part-time shoulder use
Vertical clearance	Green Book – Shall be 16+ feet over lanes and shoulders in rural areas and at least a single freeway route through highly developed urban areas, shall be 14+ feet on other highly developed urban freeway routes Interstate Standards – Shall be 16+ feet over lanes and shoulders in rural areas and at least a single Interstate through urban areas, shall be 14+ feet on other urban Interstate routes	Possibly
Lateral offset to obstruction	Green Book – refers to AASHTO Roadside Design Guide, which specifies a minimum width of 1.5 feet. Interstate Standards – Shall be consistent with shoulder width requirements	Likely
Structural capacity	Green Book – Minimum HL 93 design loading structural capacity Interstate Standards – New bridges – HS 20, existing bridges – assess operating rating capacity for additional 20 year service life	Unlikely

Key Criteria for HSR:

- Lane Width
- Shoulder Width/Lateral Offset to Obstruction
- Cross Slope/Crown Line Location
- Vertical Clearance
- *Posted* Speed

Geometric Design – Cross Slope

Geometric Design – Cross Slope

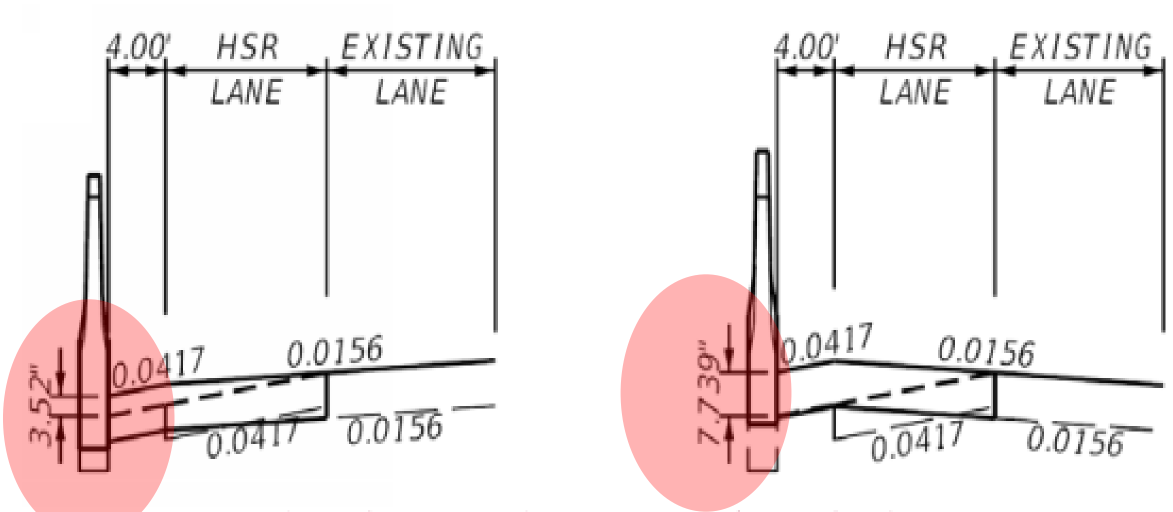


Figure 3 - Alternative #1 Normal Crown Section

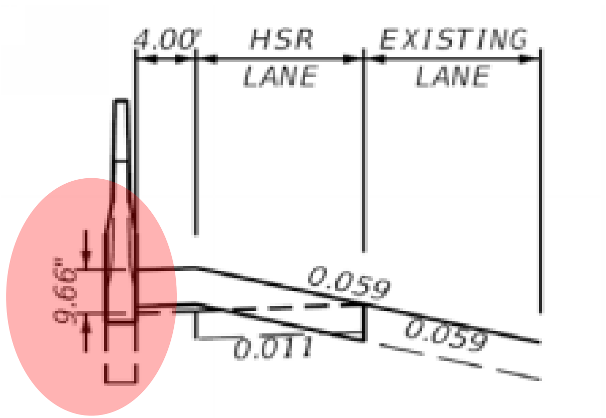
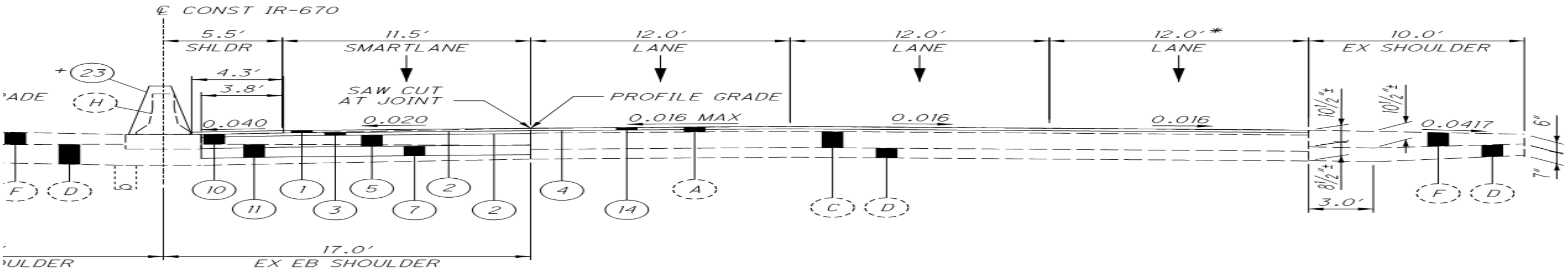


Figure 4 - Alternative #1 Superelevated Section

Pavement Design

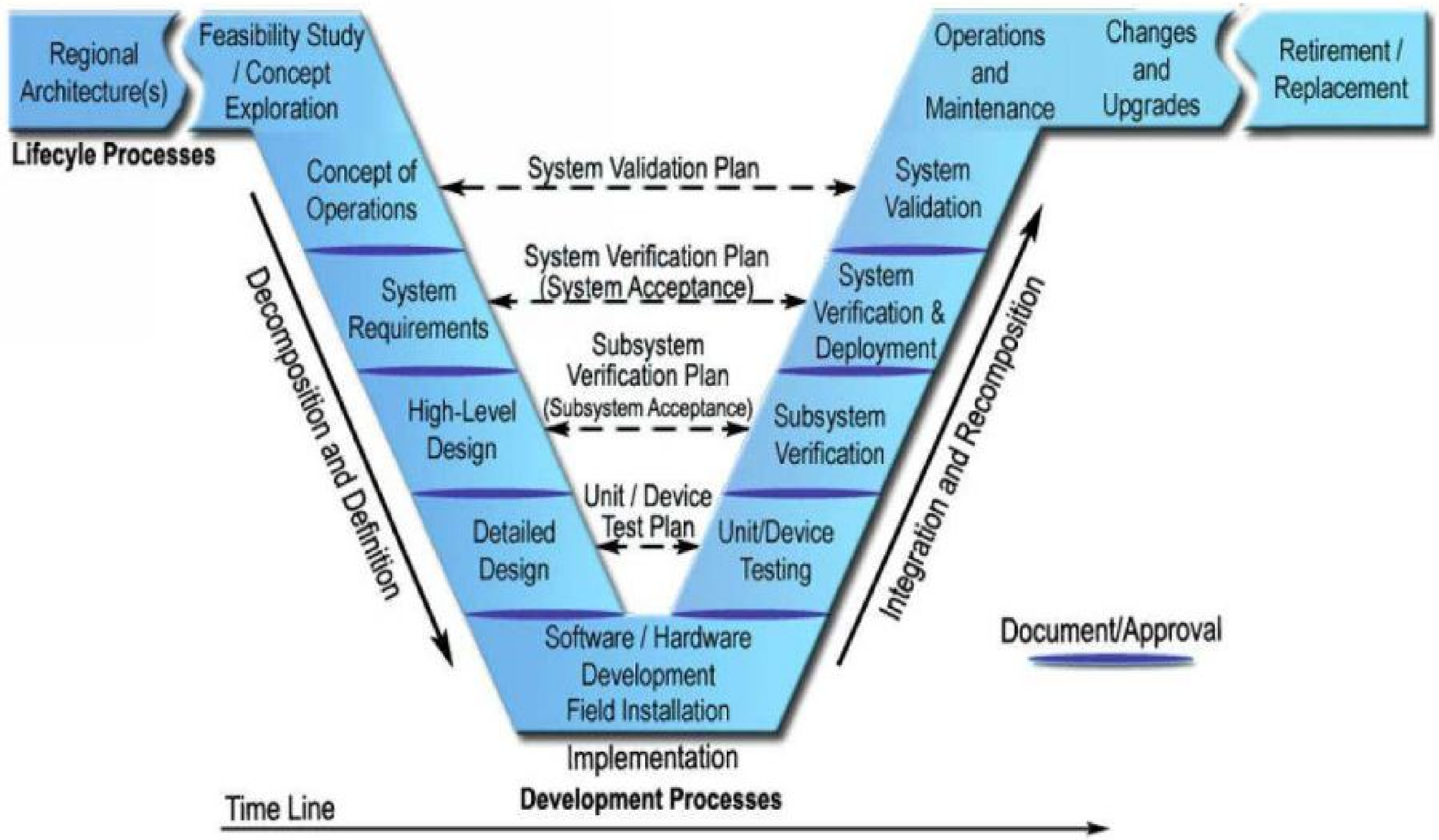
- **Existing Shoulder Pavement Depth**
- **Concrete vs. Asphalt**
  - **Construction Methods**
  - **Joints**
- **Vehicle Usage in HSR**
  - **Limit Trucks**



NORMAL SECTION - IR-670

Implementation

ConOps & Systems Engineering Analysis



Design Exceptions

- Needed if Minimum Controlling Criteria is not met
- Explain why it is infeasible to meet Controlling Criteria
- Identify Mitigation Strategies
  - Reduced Speeds
  - Increased Patrol
  - Prohibit Trucks
  - Emergency Pull-Offs
  - Rumble Strips
  - Wider Pavement Markings
  - Barrier Reflectors

Stakeholder Engagement

- **Wide Range of Stakeholders**
  - Planning, Operations, Design, Maintenance staff with DOT
  - Law Enforcement
  - Emergency Responders
  - Transit Agency
  - MPO Staff
  - Local Agency
  - FHWA Division Office
- **Education and Outreach**
  - Workshops
  - Peer Exchanges

Public Involvement

- General Reaction
  - Unfamiliarity with the concept
  - What are the Details (is the shoulder open/closed, how do I know when to get in, is speed limit changing, what if I break down?, etc.)
- Workshops, Forums, Local Council Meetings
  - Commuter traffic
- Various Media Campaigns

Public Outreach

What is Being Done?

The Michigan Department of Transportation (MDOT) is implementing new Flex Route technology to manage congestion and improve safety along US-23 in Washtenaw and Livingston counties between M-14 and just south of M-36.

Michigan's first Flex Route will use a lane control system comprised of overhead signs, cameras, and electronic message boards mounted on large gantries. The system will manage freeway traffic more efficiently during peak hours by opening and closing the median shoulder to traffic. This will promote safety by providing drivers with advance notice of delays and incidents ahead.

Crash investigation sites also will be constructed along the Flex Route area to provide a safe refuge for motorists, law enforcement and public service vehicles after an incident. In addition, the Freeway Courtesy Patrol will be active along the corridor to provide assistance and clear incidents safely and quickly.

When Will This be Done?

Construction started in November 2016, with the goal to complete the project by the end of 2017.

How Will We Keep Motorists Informed?

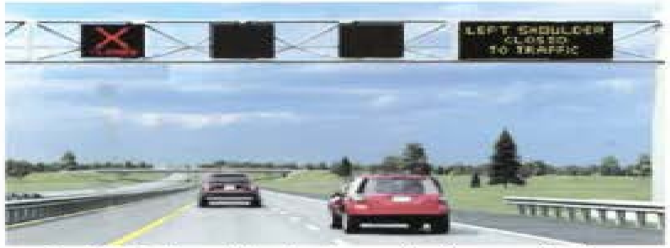
For up-to-date information on this project, go to www.michigan.gov/drive or download the free Mi Drive app from iTunes and Google Play.

Additional project information can be found at www.flexroute23.com, www.facebook.com/michigandot, and www.twitter.com/mdot_a2.

FlexRoute23
MICHIGAN DEPARTMENT OF TRANSPORTATION

Dynamic Lane and Shoulder Use

- **Green Arrow:** Shoulder is open to relieve congestion and improve travel.



- **Red X:** Shoulder is closed when traffic is light and there are no incidents.

Real-time Speed Advance System

- Speed is continuously monitored for traffic slowdowns.

- Recommended speeds are posted to decrease potential for crashes.

Incident Warning System

- Yellow chevron/merge signs tell motorists to move over to avoid incidents.

- Signs provide motorists with information, such as a crash or blocked lanes ahead.

Michigan DOT

Public Outreach

WSDOT

March 2017

I-405 Northbound Peak-Use Shoulder Lane Project, State Route 527 to Interstate 5

Northbound Interstate 405 experiences heavy congestion, especially in the Bothell area during the afternoon commute. With funding from I-405 toll revenue, the Washington State Department of Transportation plans to build new capacity between State Route 527 and I-5 to help manage congestion.

What will WSDOT build?
The primary focus of this project is building a new peak-use shoulder lane, which will add new capacity for general purpose traffic. The lane will extend for about 1.8 miles between SR 527 and I-5 in the northbound direction only. WSDOT will also construct one new noise wall along northbound I-405.

How will the peak use shoulder lane work?
Overhead lane control signs will display whether the peak-use shoulder lane is open to traffic. The lane will generally be open to traffic during the afternoon commute. Vehicles over 10,000 gross vehicle weight will be prohibited from using the lane, with the exception of buses.

Why not open the shoulder all the time?
The shoulder is still needed for maintenance, emergency services and vehicle breakdowns. If there is a collison or incident, the peak-use shoulder lane will be closed via the lane control signs until the problem is cleared. There will also be four emergency pullouts in the area of the peak-use shoulder lane.

Schedule
Construction start: Winter 2017
Open to traffic: Spring 2017

I-405 northbound peak-use shoulder lane visualization

The 1.8-mile peak-use shoulder lane will start at SR 527 and end at I-5.

For More Information
Craig Smiley
I-405 Corridor Public Information
600 108th Avenue NE, Suite 405
Bellevue, WA 98004
(425) 456-8624
Smileyc@consultant.wsdot.wa.gov

Project website:
www.wsdot.wa.gov/projects/i405/peakuseshoulder/

Washington DOT

Under Construction

I-495 North Shoulder Lane Use

From the Express Lanes merge to George Washington Parkway in Fairfax County

About the Project

VDOT began work on June 1, 2014 to improve travel conditions where the northbound 495 Express Lanes join the regular lanes.

The 1.5-mile project will allow traffic to travel on the left shoulder of northbound I-495 from where the 495 Express Lanes end to the George Washington Parkway. The existing shoulder will be rebuilt to accommodate traffic.

The shoulder will be open to all traffic during peak travel periods. A lane-use management system, with green arrows and red "X's", similar to the lane-control system on I-66, will alert travelers when the shoulder is available.

In addition, the project includes several safety enhancements such as upgraded concrete barriers in the median of I-495, new cameras and electronic highway signs to help with incident response and traveler information, and rehabilitating the pavement for a smoother ride.

All travelers and buses will benefit from the new capacity and improved merge. There will be no barrier separation between the shoulder lane and the regular Beltway lanes, ensuring easy access for travelers.

Traffic Impacts

VDOT and its contractor are making every effort to accomplish a large portion of work during nighttime hours, when traffic is typically lighter.

In general, motorists should expect lane closures to occur on this stretch of I-495 North as follows:

Daytime Lane Closures:

- Mondays through Thursdays: From 10 a.m. to 3 p.m.
- Fridays: From 10:00 a.m. to noon

Nighttime Lane Closures:

- Mondays through Thursdays: From 9 p.m. to 5 a.m.
- Fridays: From 10 p.m. to 9 a.m. on Saturday mornings
- Saturdays: From 9:30 p.m. to 9 a.m. on Sunday mornings
- Sundays: From 8:30 p.m. to 5 a.m. on Monday mornings

Occasionally, VDOT will close all lanes on this section of I-495 North for intermittent periods during overnight hours, but will work to inform the public in advance.

Cost and Schedule

Estimated Project Cost
Preliminary engineering: $3.0 million
Construction: $17.0 million
Total $20 million

Anticipated project schedule
Construction of the shoulder project began on June 1, 2014.

Area Maps

Project location

Project at a Glance

Begin Date
June 1, 2014

Est Completion Date
Open to traffic in spring 2015, final completion scheduled for June 2015

Cost
Approx. $20 million

Locality
Fairfax

District
Northern Virginia

Contact
Paul Nishimoto
Project Manager
703-259-2362
Susan N. Shaw, P.E.
Regional Transportation Program Director
703-259-1995

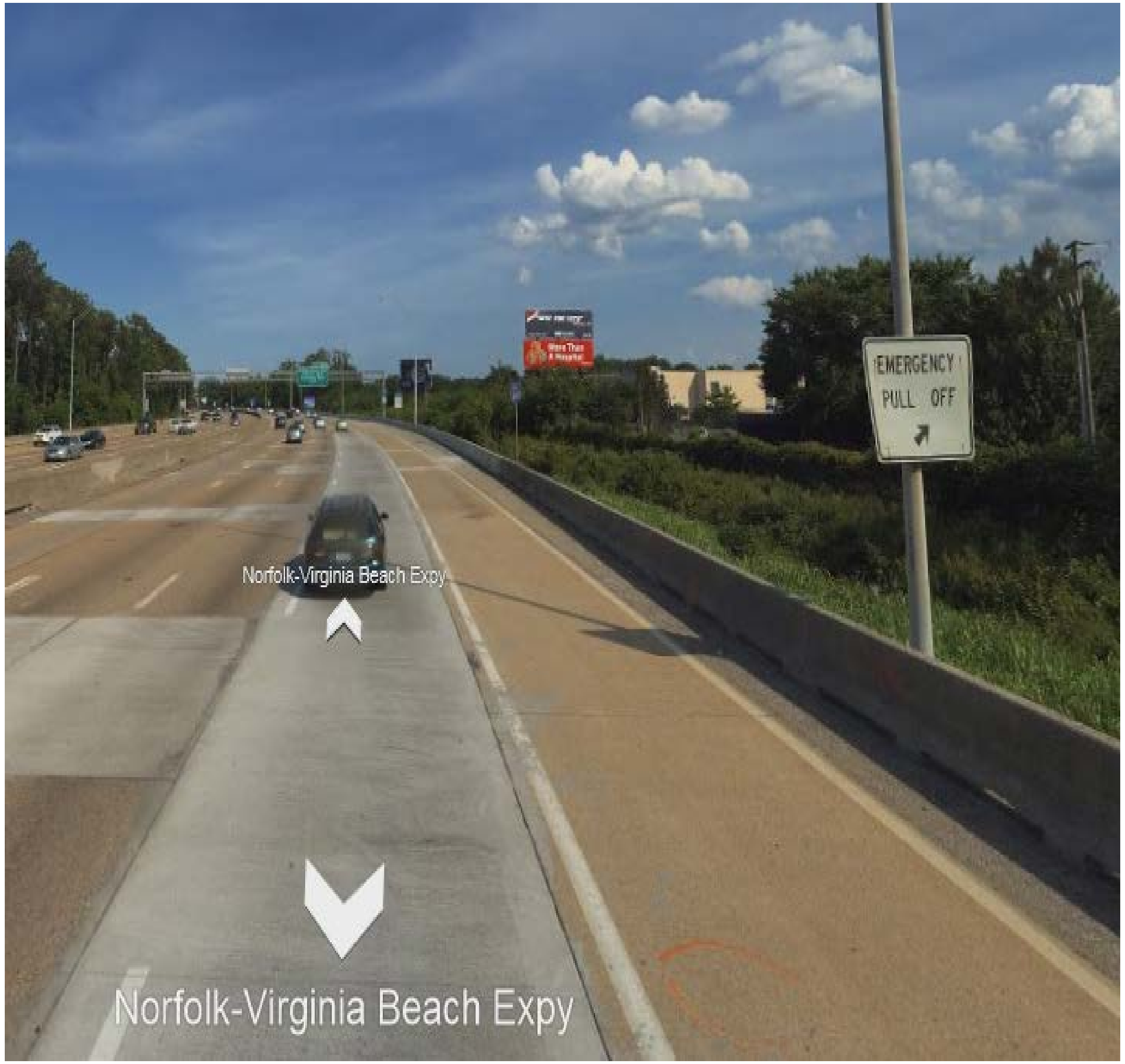
Virginia DOT

Operations

Law Enforcement

- Enforcement of improper lane usage and speed violators challenging
  - Congestion
  - Where to pull over violators
- Maintaining a shoulder to pull off is critical
- During plan development, have Law Enforcement tour the TMC
- Engage Early!

Emergency Pull-Offs - Virginia



Emergency Pull-Offs - Michigan

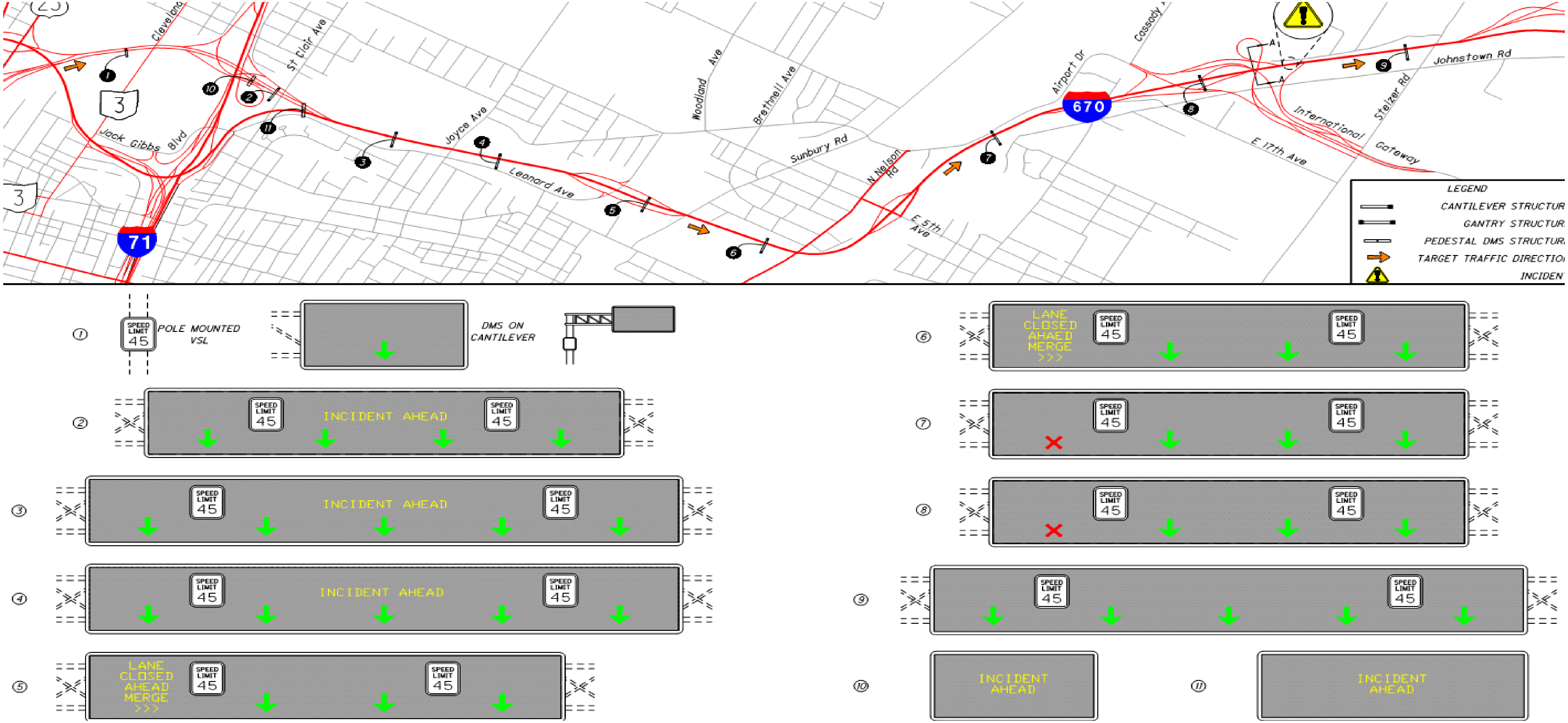
System Start-Up – Daily Sweep

Inclement Weather

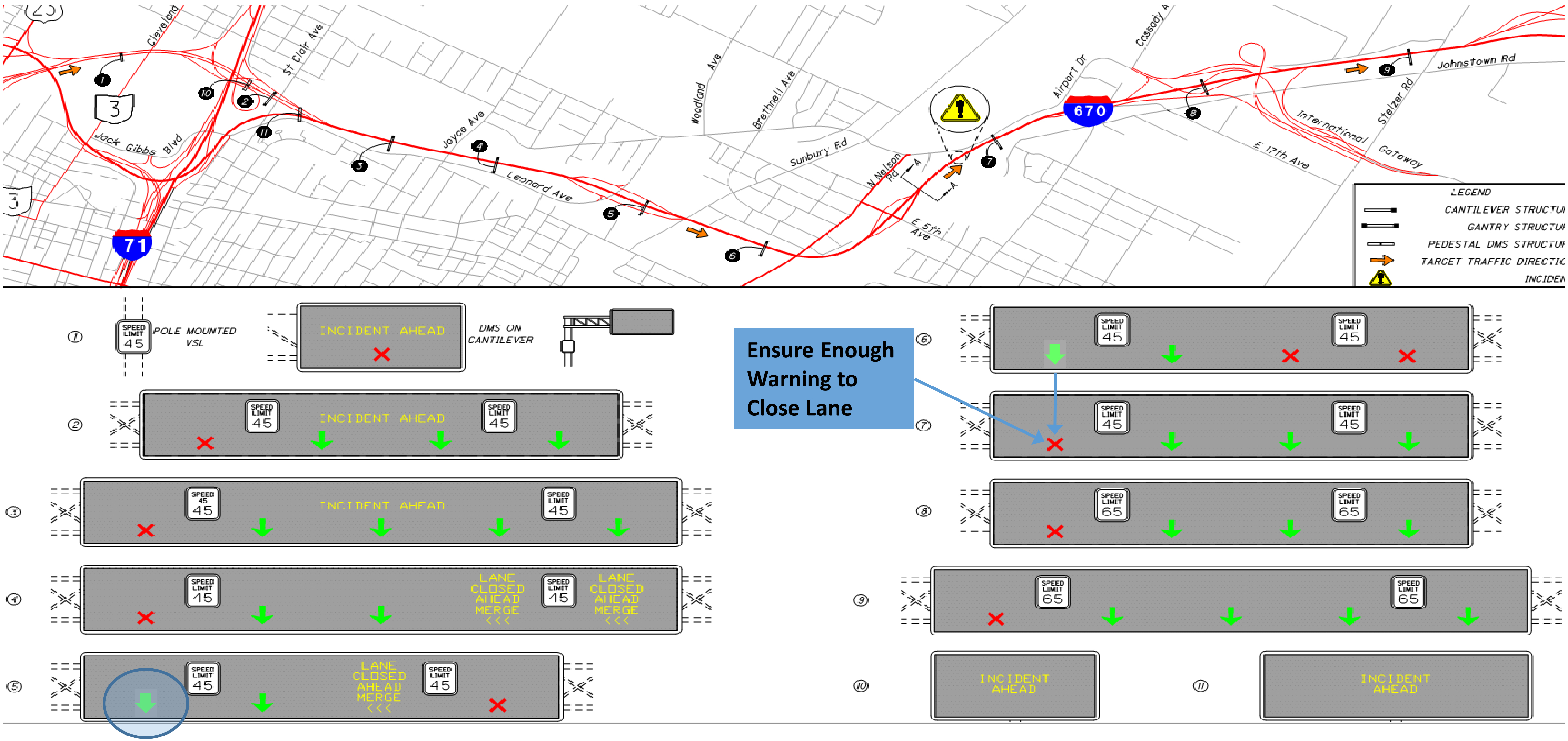
- **Shoulder should be treated as a lane**
  - **Plow frequency of shoulder should match lanes**
  - **Snow storage may require closure of shoulder until "gang plowing" can move it**
  - **During heavy rains, posted speed limits may be reduced – drainage design criteria and concern of hydroplaning**

Incident Management

Incident Management



Incident Management - Ohio



Maintenance of DMS

- **Access Without Disturbing Traffic**
  - **Catwalk**
  - **Rear access**
  - **Side access**
- **Access From Freeway**
  - **Bucket truck in lane**
  - **Front access**

Maintenance of DMS

- External Controller Unit
  - Removed from signs and placed in cabinet on side of road
  - Maintenance on side of road
  - Only filaments in the sign

Other State's Lessons Learned

Lessons Learned - Michigan

- Keep It Simple
  - Software can be complicated; simplify the number of strategies
  - External controller for the DMS allows easier maintenance and smaller/cheaper signs
- Budget Actual Costs of Project
  - Include maintenance costs when determining budget
  - Include training budget for TMC personnel
- Engage FHWA
  - Coordinate with FHWA early in the project

Lessons Learned - Virginia

- Work Closely with FHWA
  - Design Exception Process
  - Systems Engineering Analysis (SEA)
  - Conceptual Operations (ConOps)
- Better Public Engagement
  - VDOT completed Public Involvement in-house
  - Utilize staff that communicate well to ALL users, not just engineers; reach all users through technology
- Emergency Responders
  - Engage during design to ensure they are accommodated

Lessons Learned - Minnesota

- Engaged FHWA early
  - Design Exception process went smoothly
- Multiple Strategies for Operations
  - Several for inclement weather
  - Several for various incidents
  - Several for various levels of congestion
  - Became challenging getting operators trained
- Public Involvement
  - Completed this in-house
  - Struggled to get education out to all users prior to opening

Lessons Learned - Washington

- FHWA Engagement
  - Didn't engage them early enough in the project process
- Documentation
  - Filed several design variances
  - Needed good documentation of the variances
  - Needed good justifications for the variances
- Public Involvement
  - Completed this in-house
  - Struggled to get education out to all users prior to opening

Screening Process

Screening Process - Planning

- Is HSR consistent with region's long-range plan?
- What is the transportation need in the corridor?
- Does the region have experience with TSM&O strategies?
- Is HSR feasible from a constructability standpoint?
- Is real-time monitoring and incident response in place?
- What are the impacts?
- Does HSR implementation reduce cost compared to traditional projects?
- How can HSR be designed and operated to optimize benefits and mitigate impacts?

Screening Process – Pre-Engineering

- **Does the paved shoulder width meet minimum widths for carrying traffic?**
  - If not, lower speeds or prohibit trucks?
- **Do bridges over the shoulder meet minimum clearance height requirements?**
  - If not, special vehicle-height restrictions necessary?
- **Is the shoulder pavement depth sufficient for carrying traffic?**
  - If not, prohibit trucks/heavy vehicles?
- **Is the drainage system compatible with shoulder use?**
  - If not, modify drainage or lower speeds?

Screening Process – Pre-Engineering

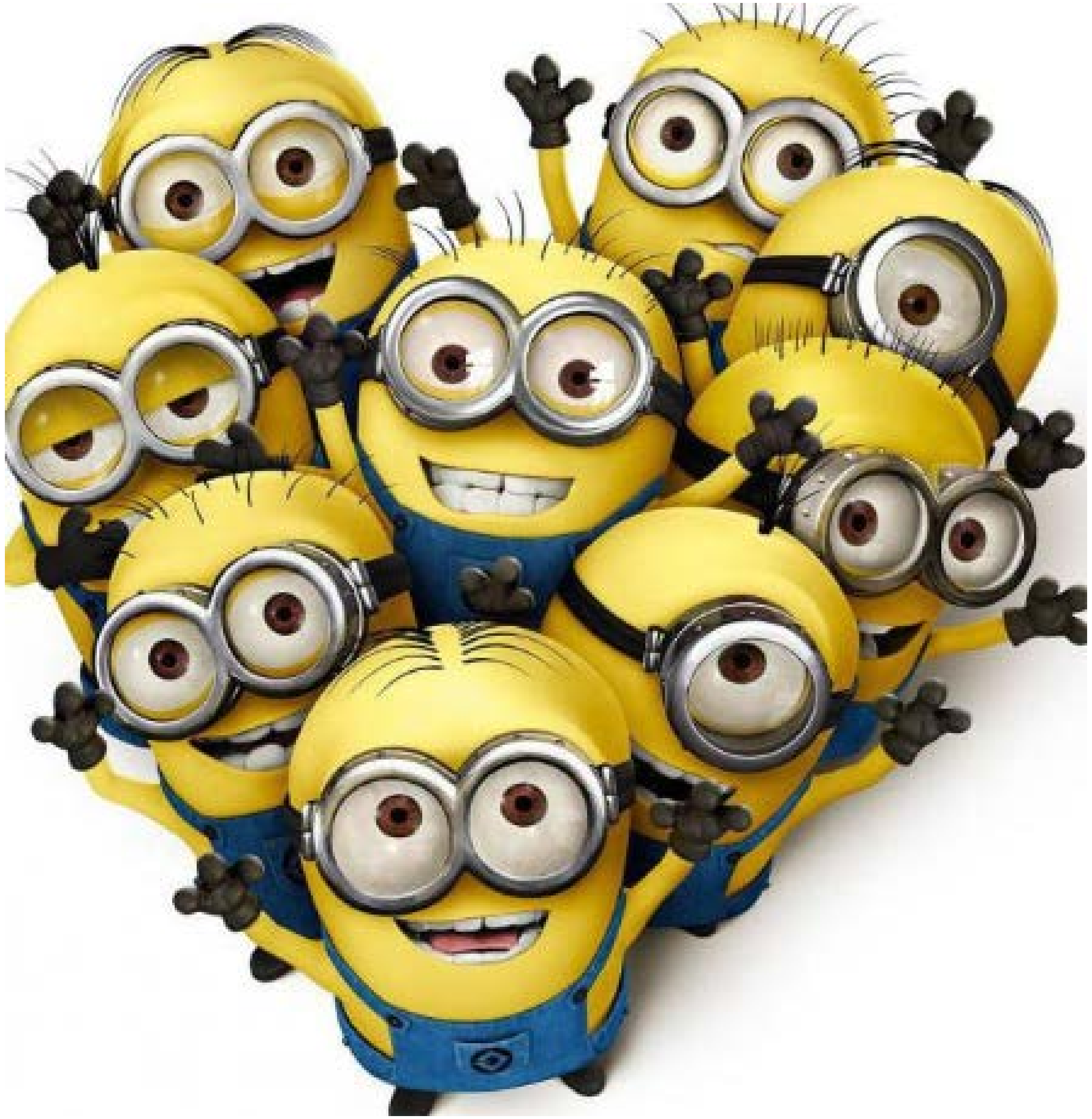
- **Do the bridges along the corridor provide enough lateral width for shoulder use?**
  - **If not, is widening an option?**
- **Is the length of the HSR segment long enough to provide meaningful congestion relief?**
  - **If not, is the segment addressing an acute bottleneck?**

- **Can safety concerns be resolved?**
  - **Can ramp merge visibility and merging distance issues be resolved?**
  - **Can substandard geometry be mitigated through lower speeds, vehicle restrictions, or ATM?**
  - **Can the concerns of emergency first-responders and maintenance personnel be resolved?**

Potentially Good HSR Candidates

- Reliable and repeatable periods of congestion
- Lateral width to accommodate HSR implementation
- Minimal widening of bridges along the corridor
- Minimal corrections to overhead bridges in order to fit the HSR cross section under
- Prefer a long corridor for HSR implementation
- Prefer full-depth existing shoulders
- Prefer ITS-compatible corridor
- Prefer tangential alignments or horizontal curves where HSR is on the outside
- Prefer to minimize R/W impacts

Questions?



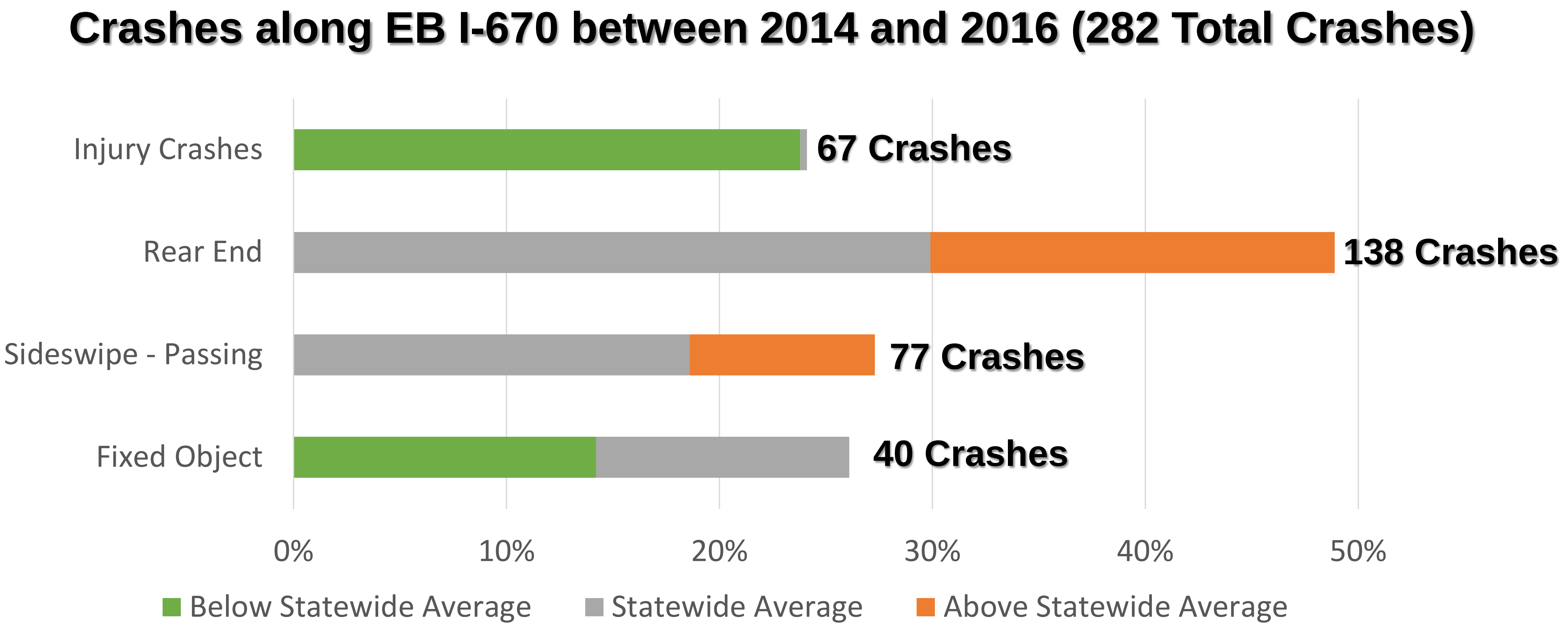
Contact:

Emilie Worley, PE, PTOE
Burgess & Niple, Inc.
614-459-2050 (o)
emilie.worley@burgessniple.com

Brian Toombs, PE
Burgess & Niple, Inc.
614-459-2050 (o)
614-946-9343 (c)
brian.toombs@burgessniple.com

Extra Slides

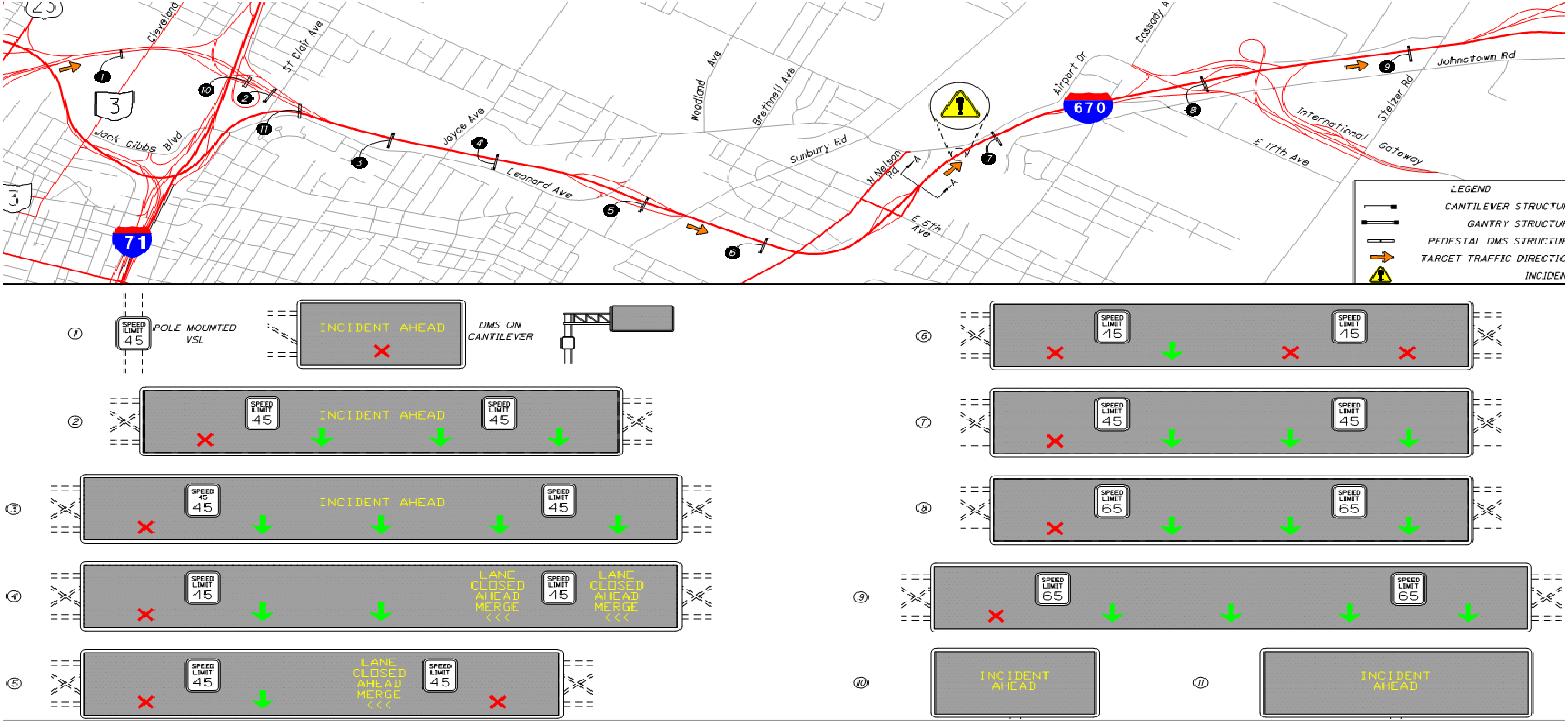
Safety Analysis – Case Study in Ohio



Incident Management

Incident Management - Ohio

Incident Management - Ohio



Where is HSR Implemented?

Table 13. Part-Time Shoulder Use Facilities in US.

Strategy	Location	Corridor	Length (miles)	Year Deployed	Vehicle Type	Usage Criteria	Maximum Allowed Speed	Lane Width (feet)	Note
Static	Alpharetta, Georgia	GA 400	12	2005	All	General purpose lane speeds drop below 35 mph	35 mph max, speed differential with general purpose lanes below 15 mph		Previously buses use only, freeway application
	Boston, Massachusetts	I-93, I-95, SR 3	45	1985	Passenger vehicles only	M-F, 5- 10am, 3-7pm	65 mph (60 mph on SR 3)	10-12	Freeway application, shoulder running has been eliminated on several miles of I-95 after road widening
	Fairfax County, Virginia	I-66	6.5	1992	All	M-F, 5:30- 11am (EB), 2-8pm (WB)	55 mph	12	Freeway application
	Virginia Beach, VA	I-264	3.5	1992	All	M-F, 6-8am (EB), 4-6pm (WB)	55 mph	10	Freeway application
	McLean, Virginia	I-495	1.5	2015	All	7-11 am, 2- 8pm	55 mph	11	Planned left- shoulder application
	Everett, Washington	US 2 EB	1.22	2009	All	M-F, 3-7pm	60 mph	14	Arterial application
	Honolulu, Hawaii	I-H1			All	Morning peak period			Temporary condition until high-cost capacity improvements are implemented, freeway application
	Seattle, Washington	US 2	1.55		All	Evening peak period	Same as general purpose lane		Permanent application, capable to accommodating growth
	Trenton, New Jersey	NJ 29	1		Cars only	M-F, 7-10am	Same as general purpose lane	13	Additional exit lane to NJ 129 (creating 2 lane exit)
	Newark, New Jersey	I-78 EB	7	2014	All	Peak periods	Variable, but same as general purpose lane	12	Temporary due to closure of adjacent freeway for reconstruction
Dynamic	Minneapolis, Minnesota	I -35W	2.5	2009	Dynamic priced		Freeway free- flow speed	17-19	Freeway application
	Fairfax County, Virginia	I-66	6.5	2015	All		variable	12	Was static from 1992-2015

Source: FHWA (Use of Freeway Shoulders for Travel)

Origin of HSR

- Performance-Based Practical Design
- Transportation Systems Management and Operations (TSM&O) Strategies
  - Work Zone Management
  - Traffic Incident Management
  - Service Patrols
  - Special Event Management
  - Road Weather Management
  - Transit Management
  - Freight Management
  - Traffic Signal Coordination
  - Traveler Information
  - Ramp Management
  - Managed Lanes
  - Part-Time Shoulder Use

Origin of HSR

- **Active Traffic Management**
  - **Dynamic Speed Limits**
  - **Adaptive Ramp Metering**
  - **Dynamic Lane Assignments**
  - **Queue Warning**
  - **Dynamic Rerouting**
  - **Adaptive Traffic Signal Control**
  - **Dynamic Lane Use/Shoulder Control**

Benefit/Cost Analysis of HSR

- Typical Benefits:
  - *Reduced Travel Times*
  - *Reduced Delay*
  - *Reduced Fuel Consumption*
  - *Reduced Number of Crashes*
- To Monetize Benefits, FHWA *TOPS-BC* tool is a good source
  - Spreadsheet-based tool
  - HSR is one of the strategies – identified as *ATDM Hard Shoulder Running*

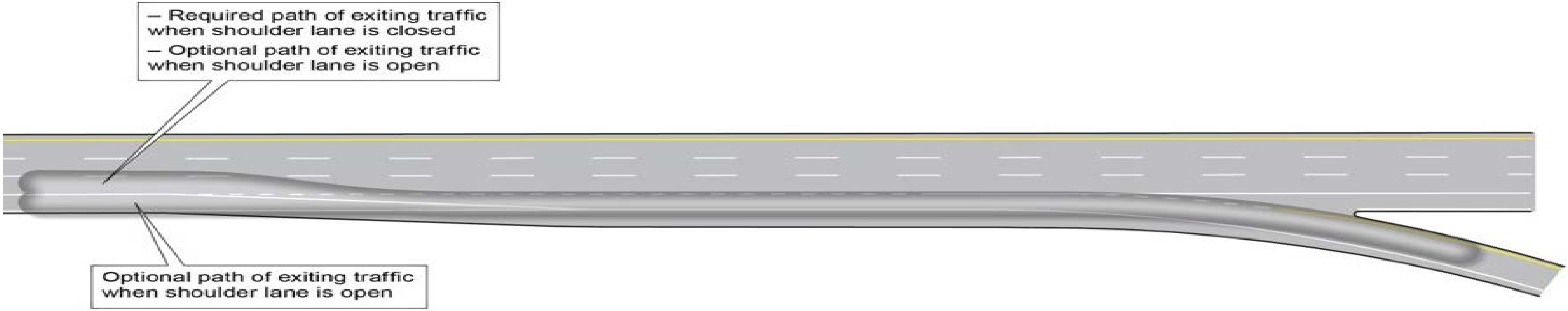
Benefit	Specific Condition	Valuation
Delay (per hour)	"On the clock" travel	$ 30.91
	Other auto travel	$ 15.46
	Truck travel	$ 30.91
Crashes (per occurrence)	Fatality	$ 9,936,727
	Injury	$ 73,973
	Property damage only (PDO)	$ 2,539
Fuel Use	Per gallon (excluding taxes)	$ 4.05
Non-fuel Operating Costs (per VMT)	Auto	$ 0.25
	Truck	$ 0.37
Emissions (per ton)	CO	$ 77
	CO2	$ 41
	Nox	$ 17,997
	PM10	$ 145,518
	VOC	$ 1,259
Noise (per VMT)	Auto	$ 0.0012
	Truck	$ 0.0364

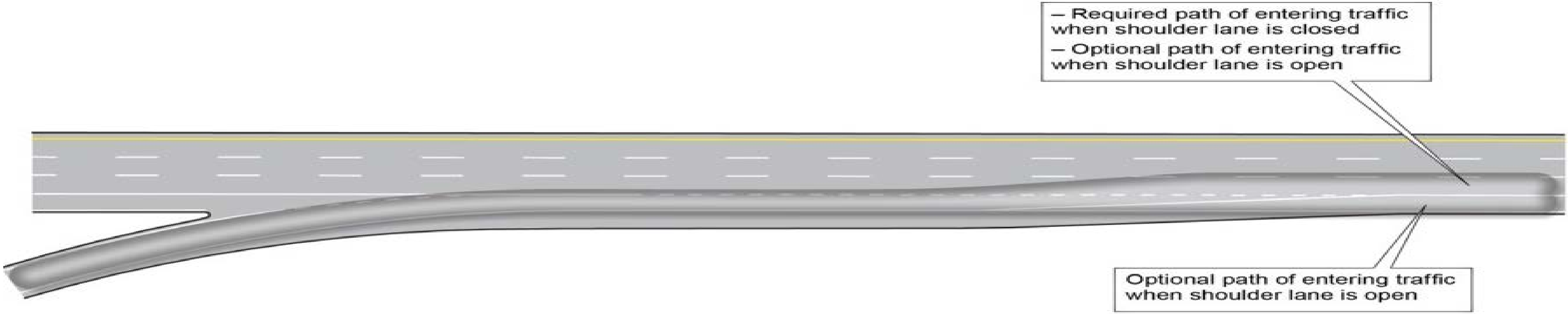
Note: From TOPS-BC Tool, assuming 2015 dollars and a 2% inflation rate

Pavement Marking Design

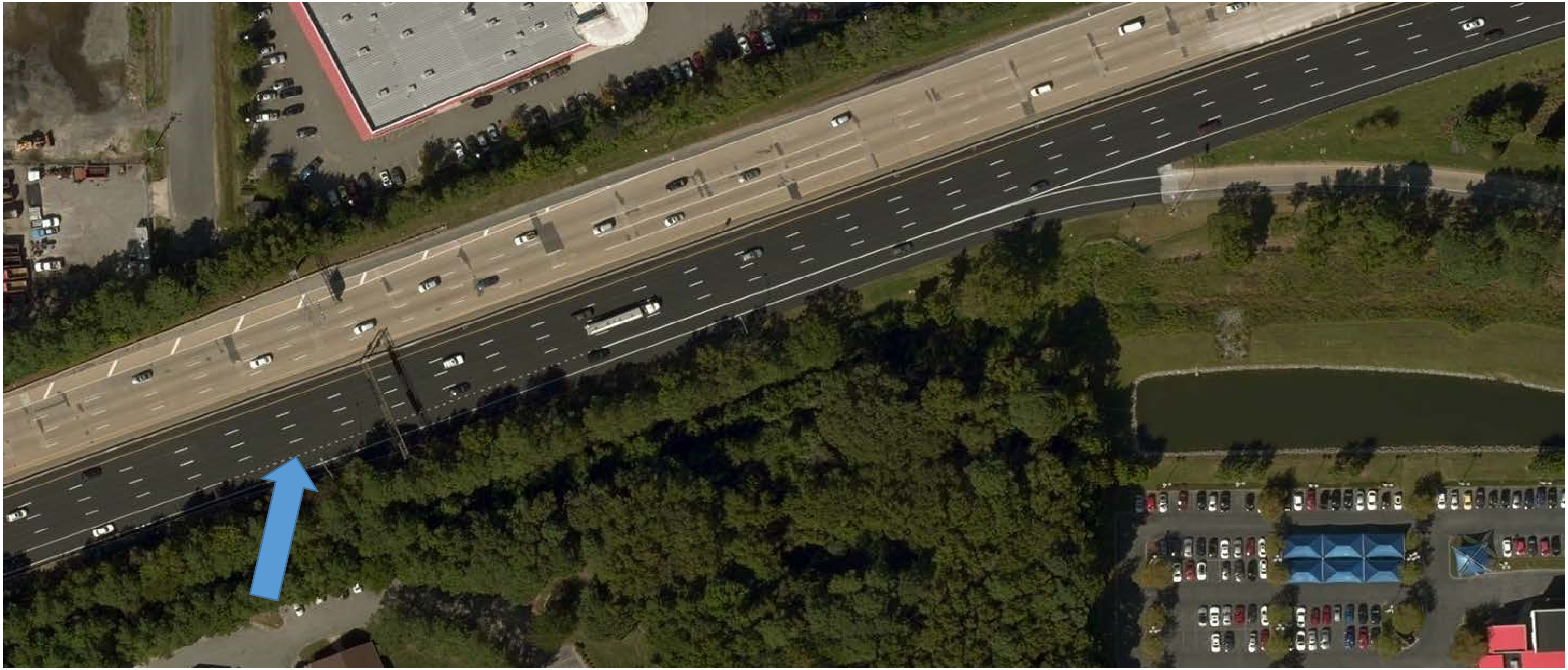
- **Pavement Markings must be clear**
  - **Entry and exit locations; different for left and right shoulder use**
  - **Use of color to differentiate lane use (MUTCD experiment)**
  - **Pavement tattoos**

Pavement Marking Design – Ramps

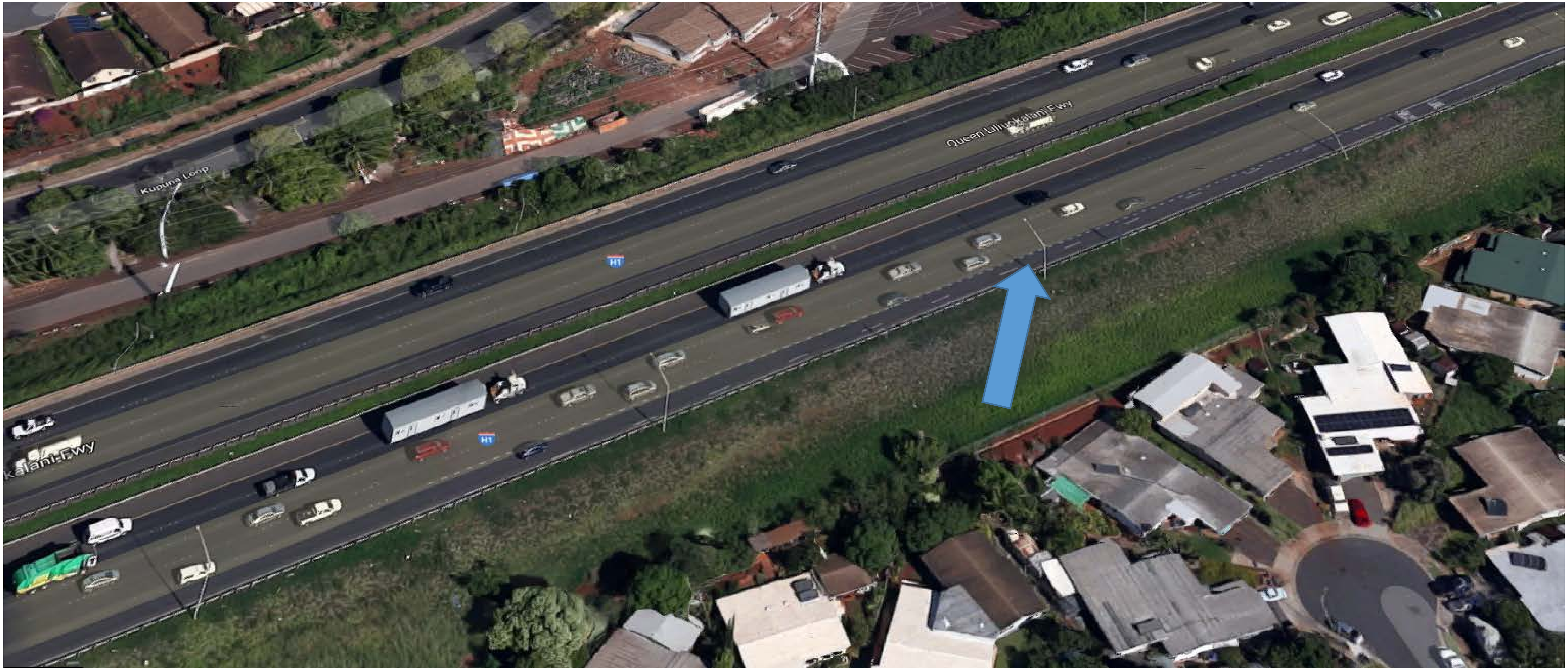




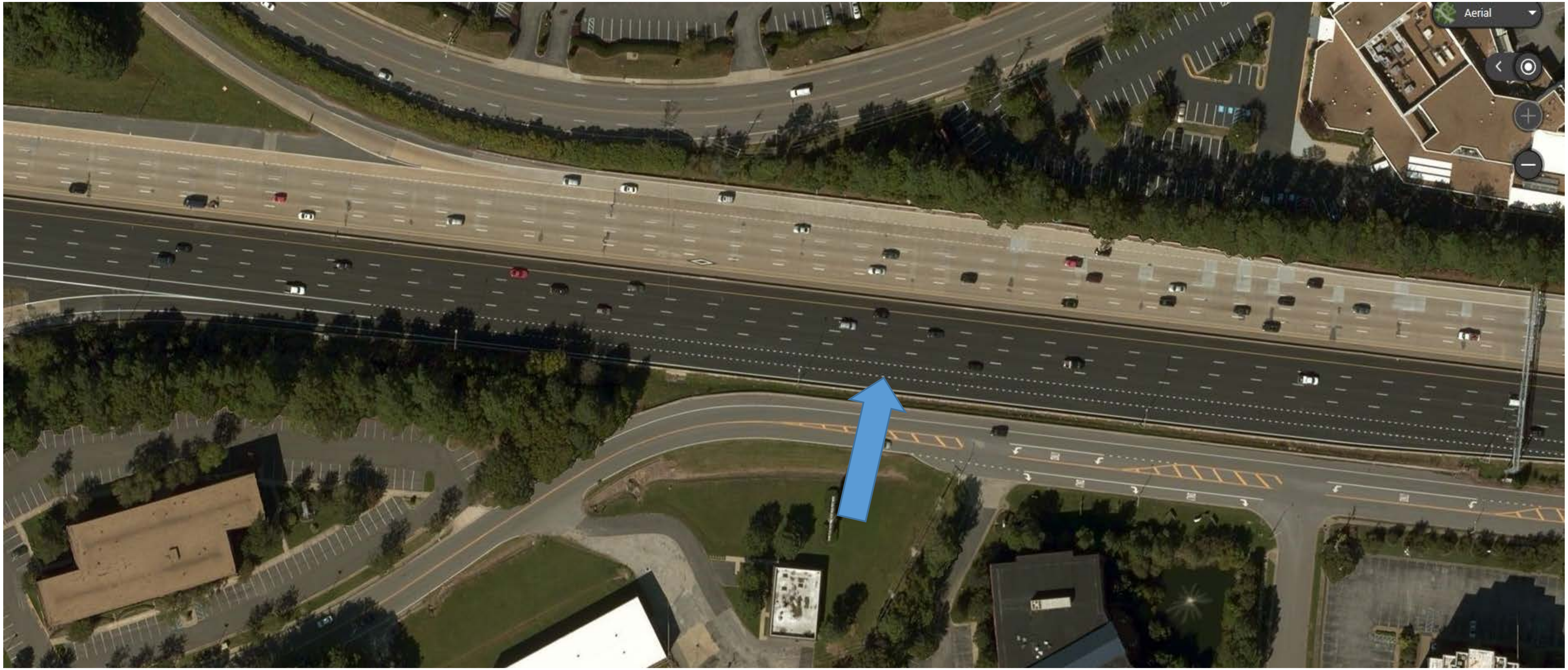
Pavement Markings – Exit Ramps



Pavement Markings – Entrance Ramps



Pavement Markings – Entrance Ramps



Safety Analysis – Case Study in Ohio

"Analyzing a shoulder in use for part of the day would require knowledge of the hours of operation and the percent of AADT during those hours. Models would be run twice, and a weighted average could be computed."